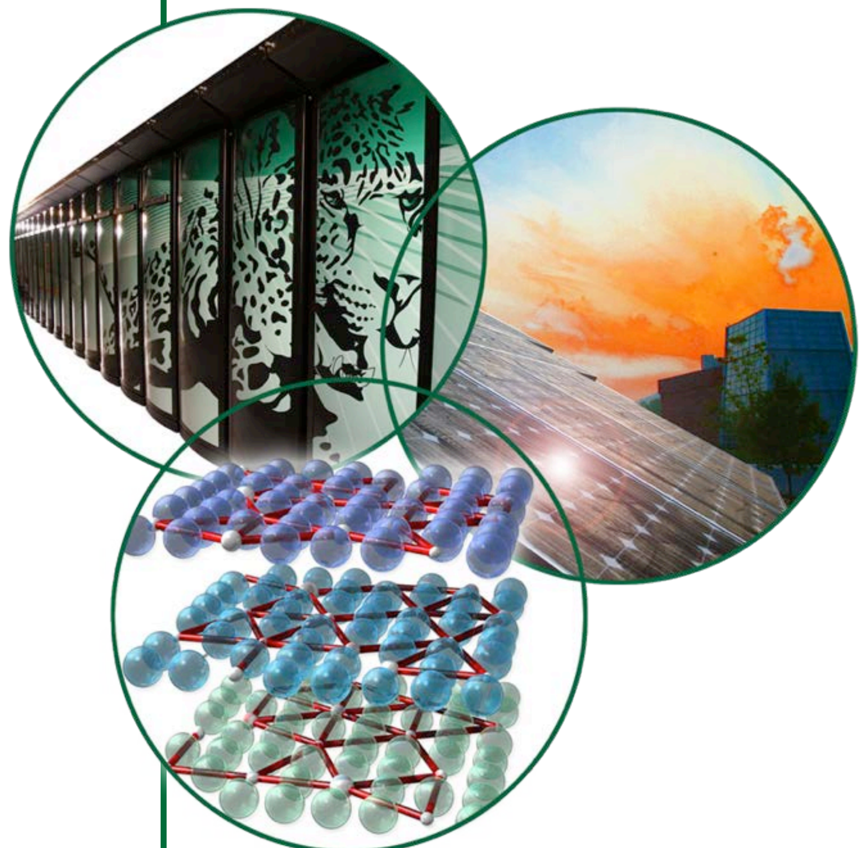
Friction Reduction Through Surface Modification
(Agreement ID:23284)

Project ID: PM052

ORNL: Peter J. Blau (retired), Kevin M. Cooley, and Jun Qu

DOE HQ Program Manager: Jerry Gibbs

2014 DOE Vehicle Technologies Program Annual Merit Review, June 19, 2014



Overview

Timeline

- Project start date: Oct. 1, 2010
- Project end date: Sept. 30, 2014
- Percent complete: 90%

Budget

- Total project funding: $1,135K
- FY13 funding: $235K
- FY14 funding: $150K

Barriers

- 10-15% energy generated in an heavy-duty diesel engine is lost to parasitic friction.
- Low-viscosity engine oils increase fuel economy but post wear challenges, e.g., bushings/bearings of connecting rods.
- Target: reducing friction by >20% via surface texturing and coating.

Partners

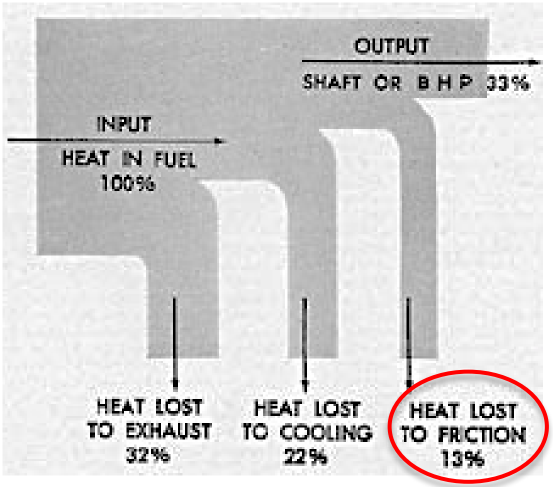
- George Washington University
- Northeast Coating Technologies

Relevance – Objectives

- Objective: To improve the fuel efficiency of diesel-powered vehicles by reducing the friction between contacting surfaces in the engine, via a combination of surface texturing and coating technology.
  - Reducing boundary and mixed friction;
  - Allowing the use of lower-viscosity engine oils to reduce hydrodynamic drag;
  - Mitigating higher peak-cylinder-pressure (PCP)-induced thinner oil film.

Relevance - Potential Payoff

- In an HD diesel engine, 10-15% of energy is lost to parasitic friction.
- 20-40% friction reduction would improve fuel efficiency by 2-6%!
- This project is intended to provide a combined surface modification technology to reduce friction losses and mitigate wear issues for HD diesel engines.
- Target components include piston rings, connecting rod end bearings/bushings, and cam followers.



Milestones

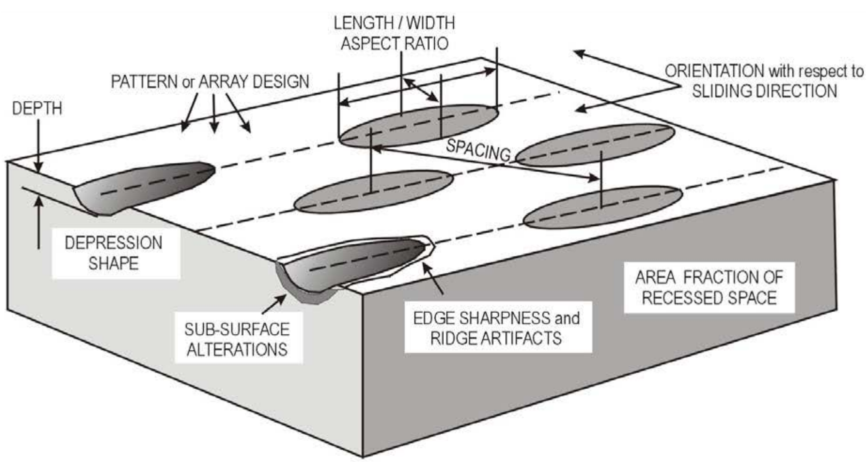
- **03/31/2013, Submit a report describing the durability test procedure to be used for textured surfaces, simulating the ring liner interface conditions. (complete)**
- **09/15/2013, Complete studies on the effects of texturing on friction in a reciprocating piston ring/liner configuration. (complete)**
- **12/31/2013, Select wear-resistant thin coatings for textured bearing surfaces. (complete)**
- **03/31/2014, Obtain friction test specimens of textured and coated specimens. (complete)**
- **06/30/2014, Complete friction tests of textured and coated surfaces in low viscosity engine oils. (in progress)**
- **10/30/2014, Submit a final report on friction reduction by texturing and coating oil-lubricated surfaces.**

Approach

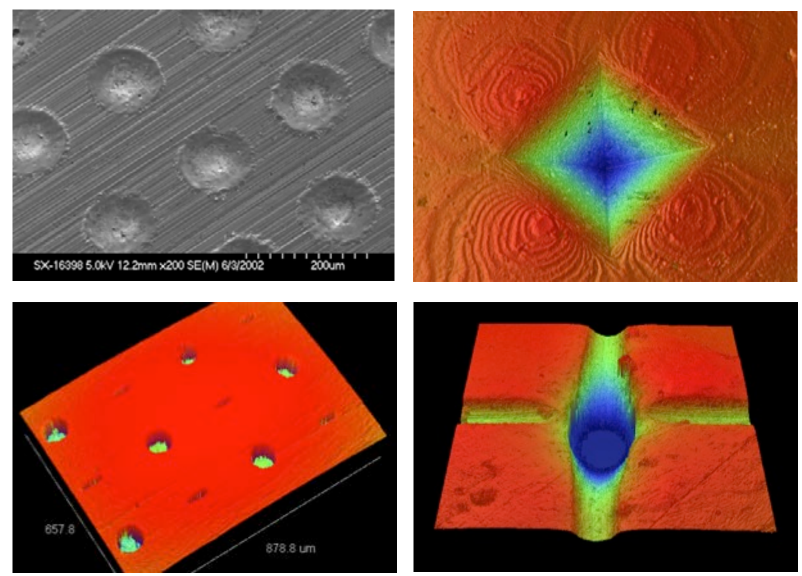
- FY 2011-2013, team the micro-texturing expertise of a sub-contractor (George Washington University) with ORNL's experience in tribology and unique friction testing capabilities. In addition, ORNL is exploring a second approach to texturing.
- FY 2014, seek synergistic effects between two friction reduction technologies: surface texturing (micro-dimpling) and diamond-like-carbon coating.

Approach

- **Functionality of surface texturing/dimpling**
  - **Alter the flow and film thickness of lubricating fluids locally and across the contact region;**
  - **Alter the bearing pressure distribution;**
  - **Serve as channels to supply lubricant to a surface; and**
  - **Trap debris that would otherwise become embedded or abrade the surfaces.**



Blau, ORNL/TM – 2012/20.



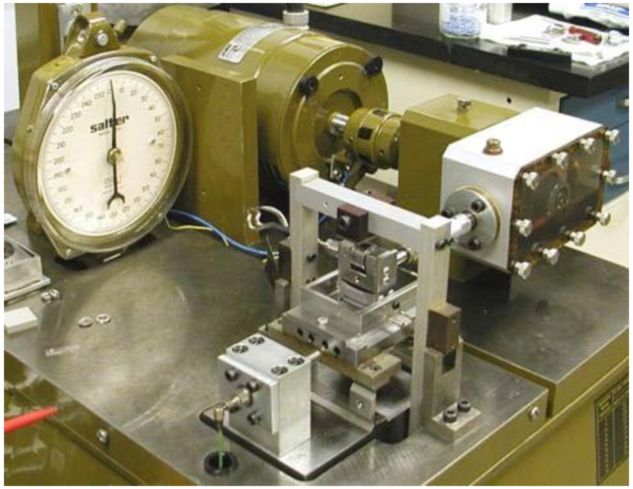
This presentation does not contain any proprietary, confidential, or otherwise restricted information

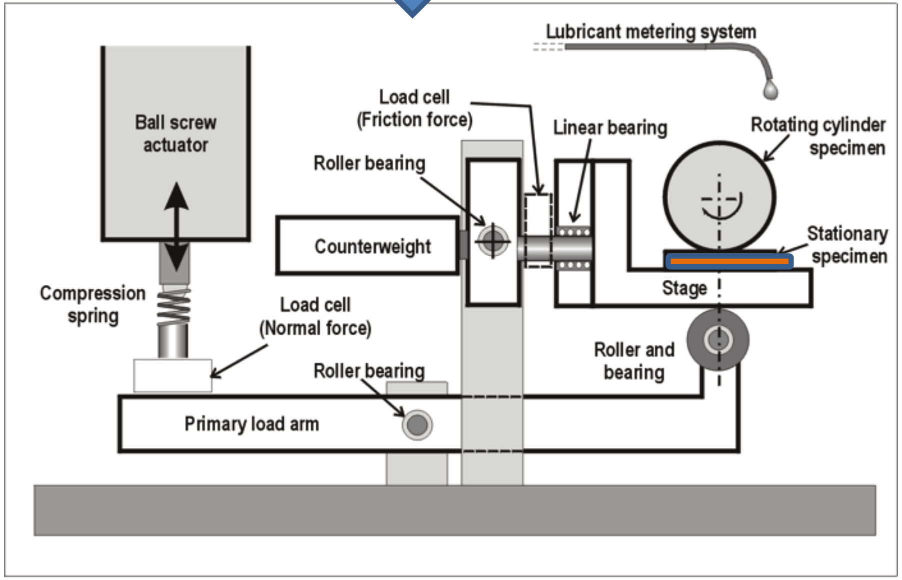
Technical accomplishments – summary

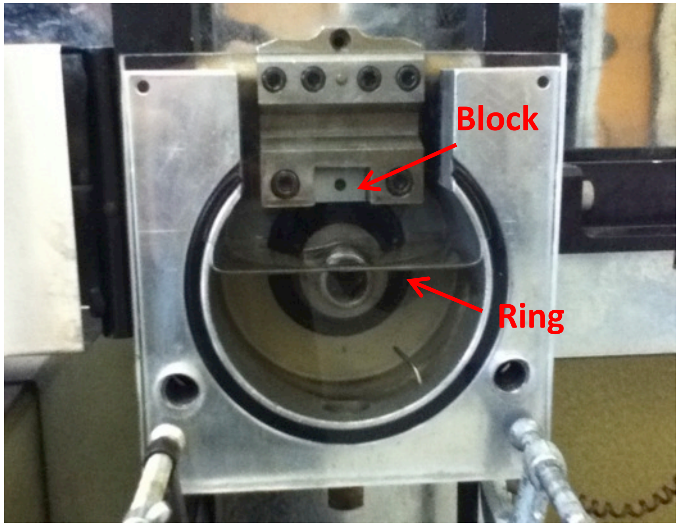
- Steel piston rings (FY 12-13)
  - GWU textured piston rings with combined circular and line dimples using photo-lithography.
  - ORNL demonstrated 5-15% friction reduction
- Bronze connecting rod end bushings/bearings (FY 13-14)
  - Multiple texturing methods were explored at ORNL
  - Wire mesh compression was selected as the top candidate due to its simplicity and the encouraging frictional results.
  - Courser texture (20x20 mesh) showed no benefit in friction behavior.
  - Finer texture (50x50 mesh) demonstrated 20-40% friction reduction in boundary and mixed lubrication.
  - Even finer textures (100x100 and 140x140 mesh) are being produced for potentially further friction reduction.
  - Developing an innovative ‘tile-like’ coating for textured bronze surfaces to address the potential wear issue.

Three test methods employed to simulate conditions for engine components

- Reciprocating motion for piston ring/liner application (ORNL and GWU)
- Block-on-ring for the cam-follower (GWU)
- Variable load cylinder on flat for the connecting rod end bearing (ORNL)



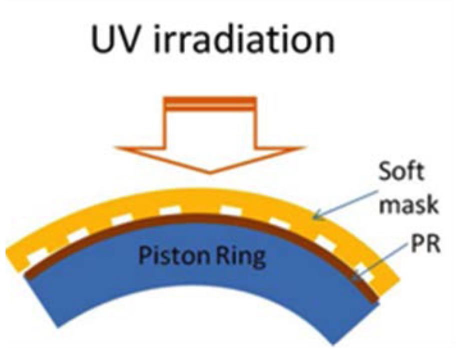




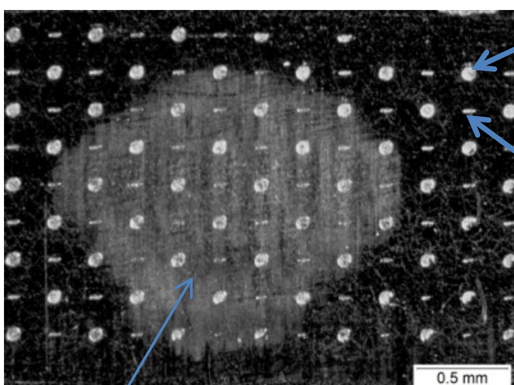
This presentation does not contain any proprietary, confidential, or otherwise restricted information

Micro-lithography for steel (piston rings)

GWU textured rings with combined circular and line dimples



Photolithography using the soft mask

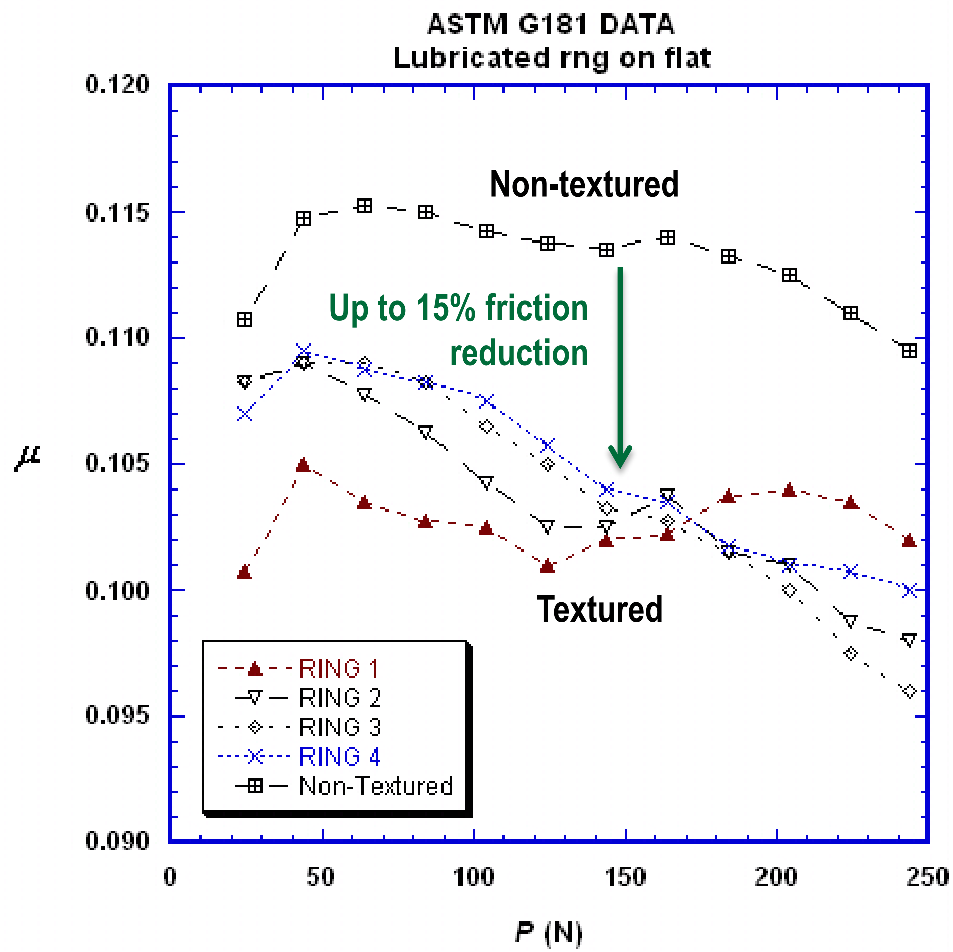


Circular dimple

Line dimple

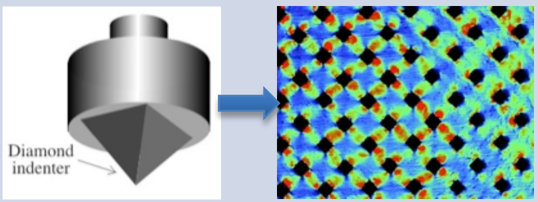
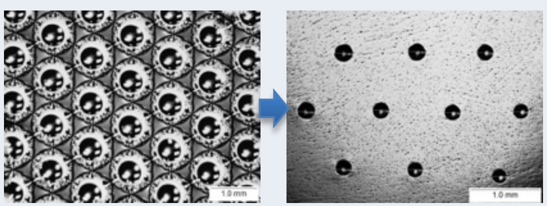
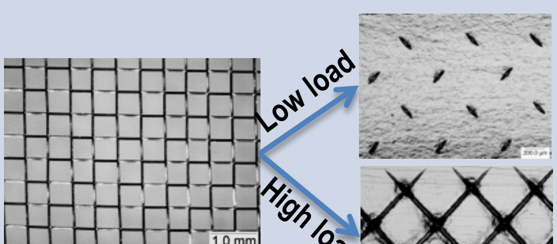
Worn contact area (frosted)

ORNL demonstrated 5-15% friction reduction



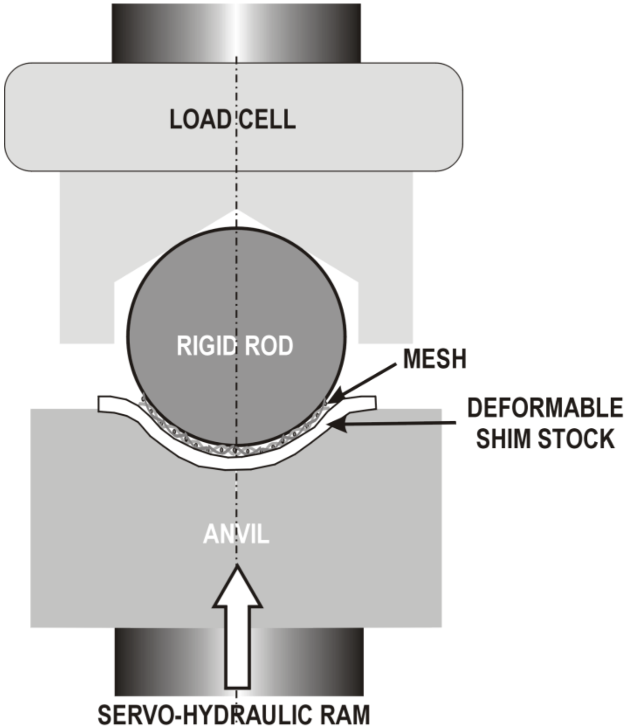
This presentation does not contain any proprietary, confidential, or otherwise restricted information

Multiple texturing methods explored at ORNL for bronze (connecting rod bushings)

Method	Observations	Status
Micro-indentation array 	Friction results not encouraging – edge issues, area fraction too small, and depth-area ratio too high. (*time consuming*)	No longer a focus of the work
Ball indentation array 	Demonstrated feasibility, but area fraction too low and shapes limited	No longer a focus of the work
Wire mesh compression  **Tungsten wire mesh**	Combinations of grooves and dimples with size control to some extent, encouraging friction results, but wear removing the texture.	Combining with diamond-like-carbon (DLC) coating to address the wear issue and potentially synergistic effects on friction reduction.

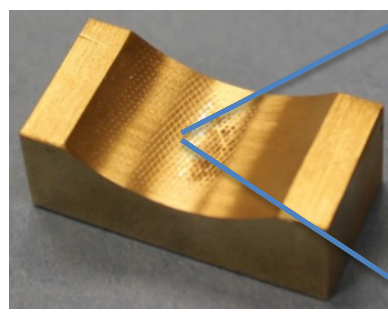
This presentation does not contain any proprietary, confidential, or otherwise restricted information

Wire mesh compression texturing process

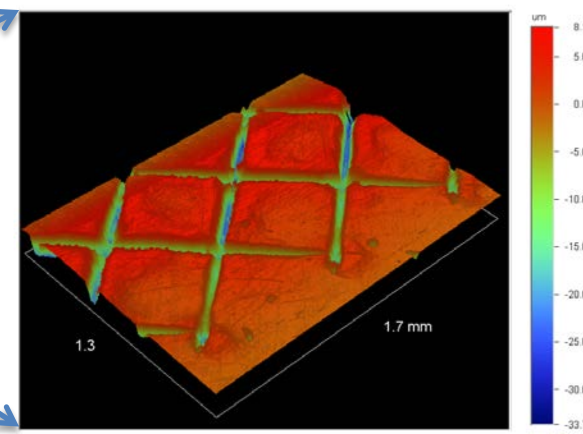


Principle of the wire mesh compression texturing

Die setup on the servo-hydraulic load frame



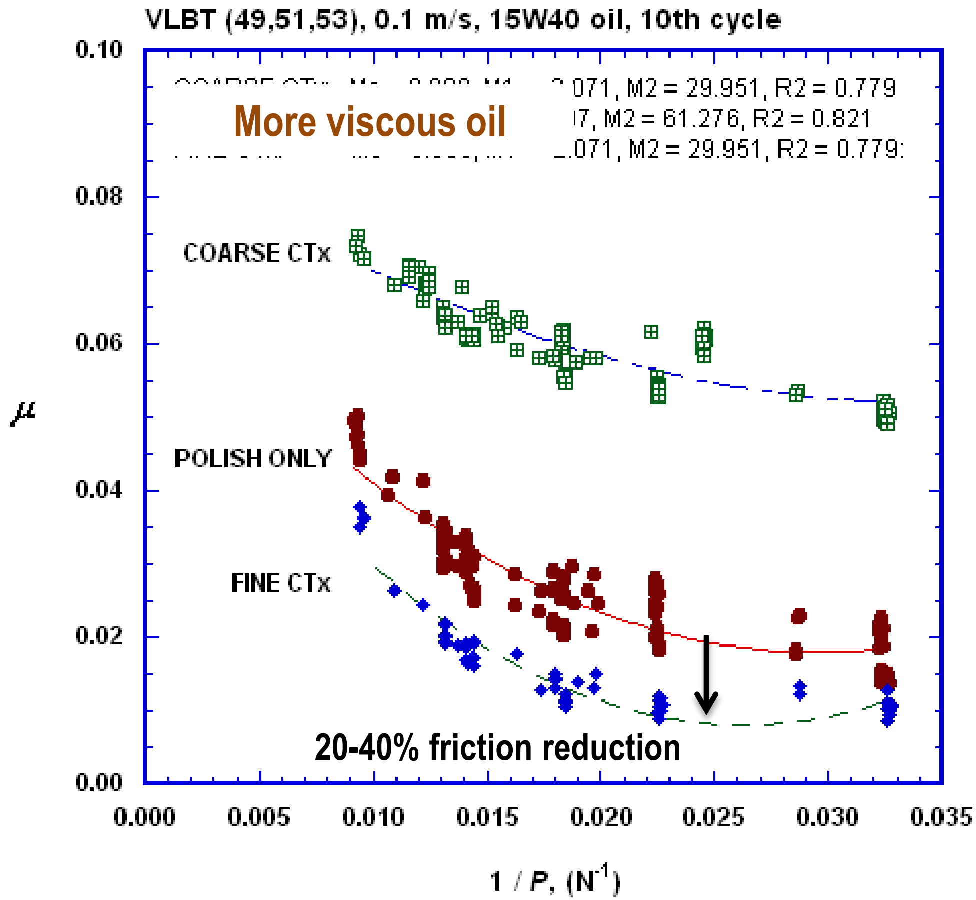
Textured sample

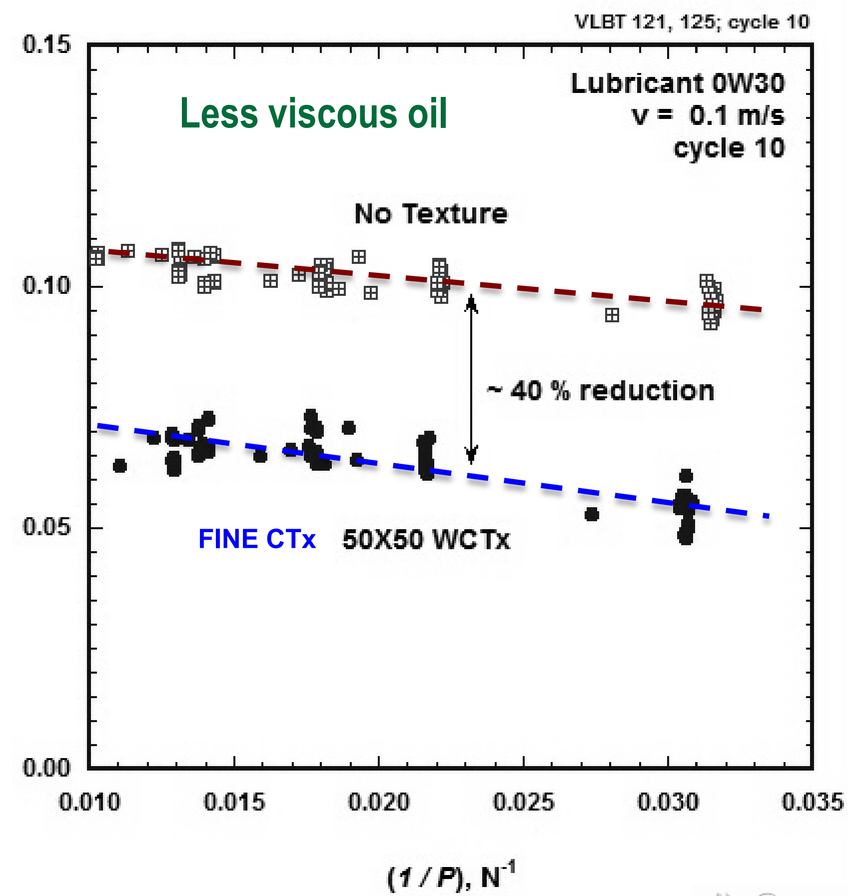


This presentation does not contain any proprietary, confidential, or otherwise restricted information

Fine texture by wire mesh compression demonstrated 20-40% friction reduction

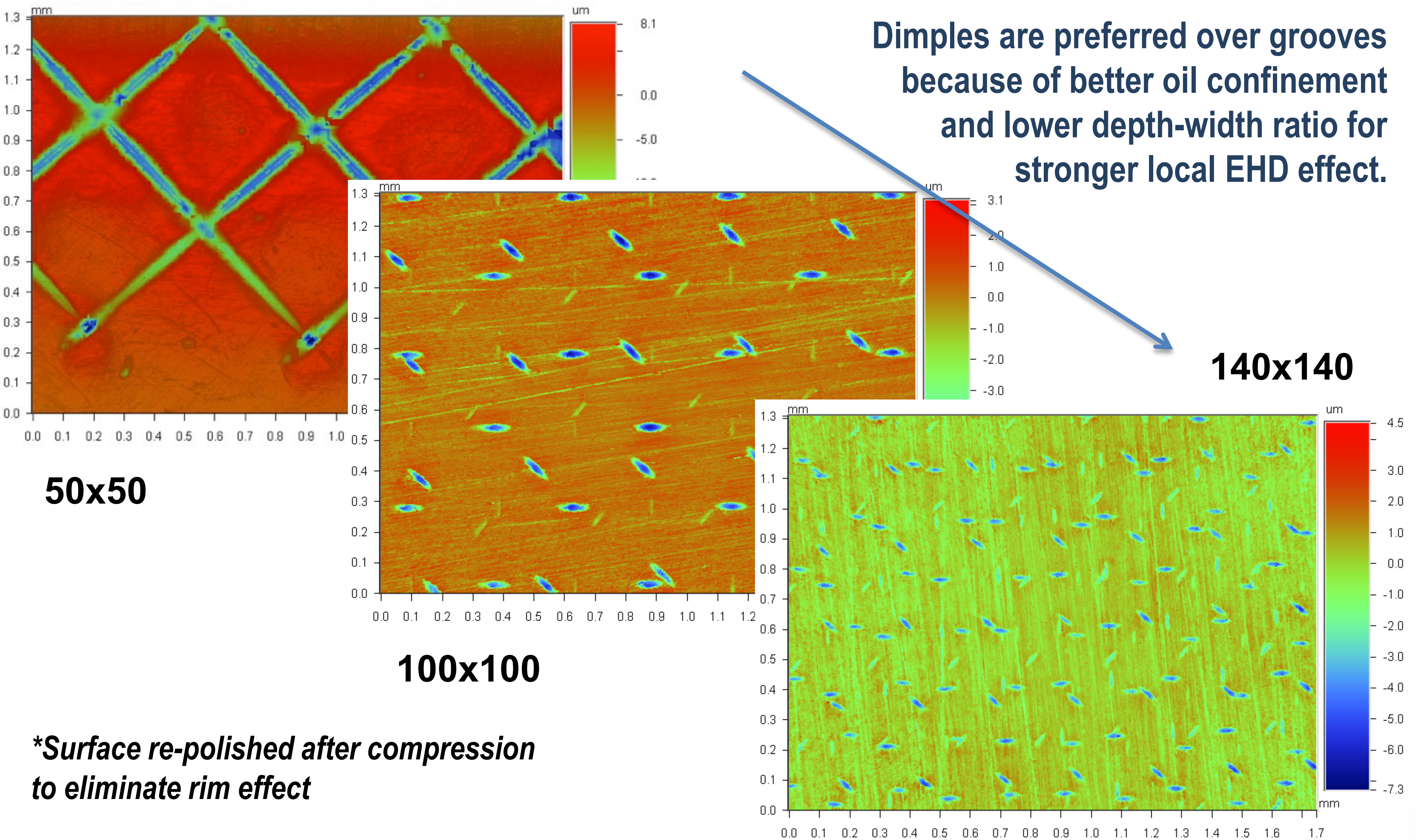
- **Fine (50x50) mesh produced a friction reduction, but coarse (20x20) mesh behaved worse than a non-textured, polished surface.**





Even finer textures being produced using 100x100 and 140x140 wire meshes

Dimples are preferred over grooves because of better oil confinement and lower depth-width ratio for stronger local EHD effect.



50x50

100x100

140x140

Surface re-polished after compression to eliminate rim effect

Responses to Previous Year Reviewers' Comments

- **Not applicable – this project was not reviewed last year.**

Collaboration

- George Washington University
  - Prof. S.M. Hsu, micro-lithography for steel piston rings
- Northeast Coating Technologies
  - Diamond-like-carbon (DLC) coating on textured bronze surfaces

Remaining Challenges and Barriers

- **Texture worn-out**
  - Although the bronze bushings/bearings mostly operate under hydrodynamic lubrication with no wear, wear is inevitable at engine start, stop, and fast acceleration when the bronze bushings/bearings operate under boundary and mixed lubrication.
  - Bronze is soft and lack of high wear-resistance. Without wear protection, the micron-level textures may be prematurely worn out to lose the frictional benefits.

○ **Mitigation: developing a 'tile-like' hard coating on the textured bronze surface**
  - 'Tile-like' coating structure is expected to allow the application of a hard coating (e.g., DLC) on a soft substrate (e.g., bronze), avoiding coating fracture or spallation.
  - DLC coated textured bronze samples have been produced and the 'tile-like' structure is being developed using two methods: 'rim polishing' and 'thermal pre-cracking'.

- **No friction reduction in elastohydridynamic or hydrodynamic lubrication**

○ **Mitigation: combining with lubricant technology**

Proposed future work

Reminder of FY 2014

- **Development of a 'tile-like' DLC coating on the textured bronze surface.**
- **Friction testing and analysis of textured surfaces (produced by 100x100 and 140x140 meshes) without and with the 'tile-like' DLC coating in low viscosity engine oils.**

Future work (if funding available): Combining advanced surface engineering and lubrication technologies for synergistic effects on friction reduction and wear control.

Summary

- **Relevance:** To improve the fuel efficiency of diesel-powered vehicles by reducing the friction between contacting surfaces in the engine, via a combination of surface texturing and coating technology.
- **Approach/Strategy:**
  - FY 2011-13, team with GWU on developing micro-texturing techniques for steel piston rings and bronze connecting rod end bushings/bearings.
  - FY 2014, seek synergistic effects between surface texturing and ‘tile-like’ DLC coating.
- **Accomplishments:**
  - Photo-lithography textured steel piston rings demonstrated 5-15% friction reduction.
  - Multiple texturing methods were explored for bronze connecting rod end bushings/bearings
  - Wire mesh compression textured bronze demonstrated 20-40% friction reduction.
  - An innovative ‘tile-like’ coating structure is being developed to address wear issues.
- **Collaborations:** George Washington University and Northeast Coating Technologies
- **Reminder of FY 2014:**
  - Development and feasibility testing of a ‘tile-like’ DLC coating on the textured bronze surface.